New Technologies for Land Imaging

Phil Dabney, LDCM Instrument Scientist
Jeff Masek, Landsat Project Scientist

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Priorities for Land Imaging Enhancements

Based on discussions with Landsat Science Team and NLIR Pilot Study, the following system enhancements have been identified:

(1) More frequent coverage (e.g. 8-day, 4-day)

(2) Improve resolution of TIR bands to 60m

(3) Provide separate 15m NIR and red sharpening bands

- *Supports higher-resolution vegetation indices*

(4) Specific additional spectral bands

- *Red-edge (0.7-0.8 μm) for Leaf-area, Chlorophyll, stress*
- *Narrow 2.2 μm bands for cellulose, lignin*
- *Water vapor (e.g. 0.94 μm)*
- *Active fire (3-5 μm)*

(5) Hyperspectral capability

(6) Higher resolution (15m) across VSWIR

Decreasing Priority

Current SLI focus is greater coverage, at lower cost, via smaller satellites

Approaches to Reducing Satellite Size & Cost

- Reduce imager bus resource load
  - Reduce imager mass and power
    - Reduce thermal management requirements
      - Warmer detector operating temps
      - Athermal metering structures and optics
    - Low power spaceflight electronics
- Shrink imagers
  - Technical limitations to and solutions for scaling down
    - Further studies into optical designs and detector issues
- Shrink space-craft bus components
  - There is a strong government and industry push in this area
- Higher integration of imagers and bus components
  - Wrap the bus around the imager (a.k.a. science craft)
- But does “smaller” really mean “cheaper”?
  - Maybe, but we need to be specific about opportunities
    - Smaller launch vehicle (but tough to do better than projected F9 costs)
    - Less costly spacecraft bus
    - Ride sharing options (e.g. ESPA, ESPA-Grande)
  - Making a smaller instrument alone (especially with exotic materials or engineering) may NOT cost less

SLI Reduced Envelope Study

- SLI has funded six contracts to study options for reducing VSWIR/TIR instrument size
  - Goal of 50x50x50cm volume, 50W, 50kg, with L8 specs (and 60m TIR)
  - Contractors asked to explore design concepts, note driving requirements, consider technologies that are likely to be available in the ***Landsat 10*** era
  - Disaggregation of TIR and VSWIR is allowed to be considered

- Awards made to:
  - Ball Aerospace & Technologies Corporation of Boulder, CO
  - Exelis Inc., Geospatial Systems of Fort Wayne, IN
  - Lockheed Martin Space Systems Company of Greenbelt, MD
  - Northrop Grumman Systems Corporation, Aerospace Systems of Redondo Beach, CA
  - Raytheon Company of El Segundo, CA
  - Surrey Satellite Technology US LLC of Englewood, CO

- 6-month studies complete March 2015

General Instrument Considerations (VSWIR)

- Telescope optics set the size of the instrument
  - The 30m resolution @ 2.2microns largely drives the minimum aperture size to approximately *10cm. (The TIR 60m drives in a combined system)
  - 15^{o} Field of view requirement limits telescope choices for a pushbroom; Whiskbroom scanners could use smaller FOV telescope designs
  - Compact fast telescope designs may be susceptible to stray light, and increased AOI variation on focal plane
- Spatial edge-slope (ie. MTF or "resolving power") is a key driving requirement
  - Techniques exist to reduce the diffraction dictated apertures at the expense of data rate, SNR, and edge response ring.
    - FPA Oversampling
    - Detector geometries
    - MTF compensation in re-sampling algorithms (aka sharpening filters)
- The inclusion of the pan band does not necessarily drive instrument envelope

General Instrument Considerations (TIR)

- 60m equivalent RER @ 12 microns drives the aperture size and overall telescope size
  - Optical Diffraction limited only considerations require an aperture of at least 16 cm
  - When “normal” detector geometries, MTFs, line scan rates, and integration times are considered, this jumps to approximately 20 cm
- Stray-light control also drives overall telescope size and design options
  - A cold stop is desired for quantum (non-microbolometer) detectors to reduce the cooling and control required for the entire telescope.
- Some form of on-board calibration is necessary
  - Drives design topography, mechanism complexity, and power

General Instrument Considerations (TIR)

- Various detector options exist, or may exist in the L-10 time frame. Each has its unique features and drawbacks
  - MCT
    - requires cooling to 60K-77K
    - lower dark level stability (requires frequent dark calibration)
    - High QE
  - QWIP's
    - requires cooling to 40K-43K
    - stable dark level (suitable for push-broom implementation)
    - Low QE
  - MicroBolometer
    - 293K operation, potentially smaller envelope and lower bus power
    - Response times support 100m resolution for push-broom; 60m is questionable
    - Markets driving toward increased sensitivity, rather than decreased response times
      - Sensitivity is still low, requiring TDI and **fast optics**
  - Strained Layer Super-lattice & nBn or XBn barrier infrared detectors
    - developing technology
    - require cooling to ~130K-150K
    - Higher QE than QWIPs

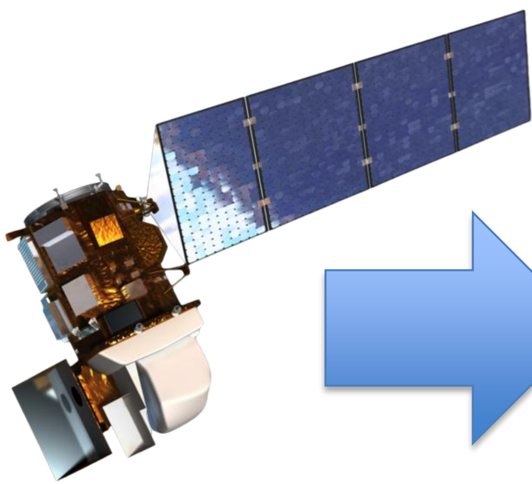
Technology Challenges to Reduce Size and Cost

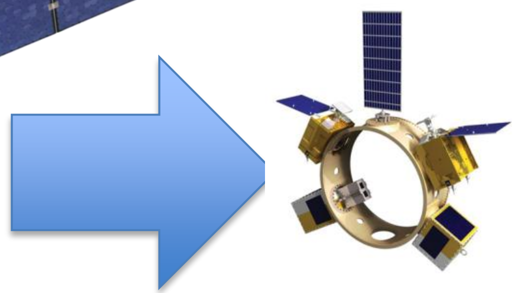
Architectures

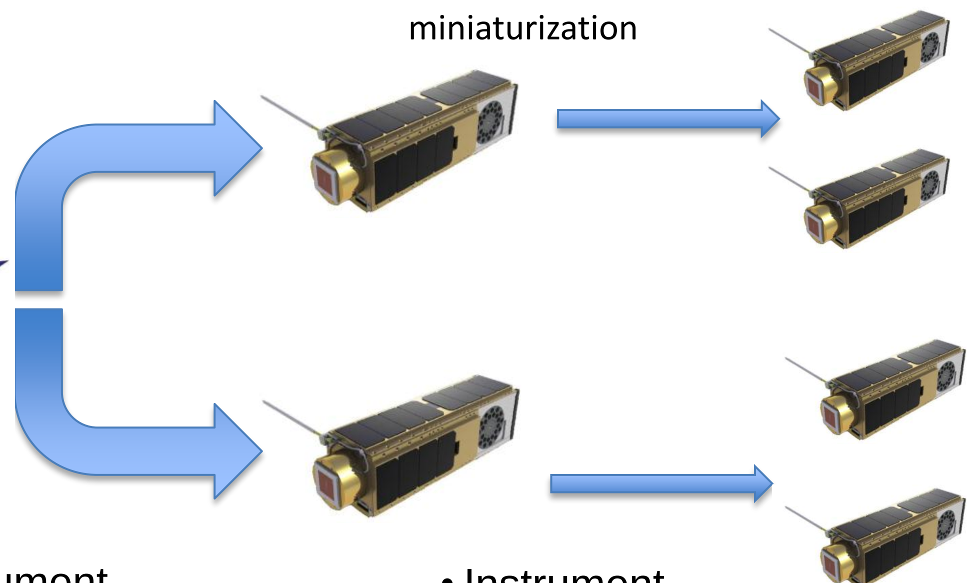
Current Landsat Paradigm	SmallSat Paradigm (<180kg)	Large CubeSat Paradigm (≥12U)	Small CubeSat Paradigm (<12U)

Key CubeSat Challenges:

- Spatial resolution (e.g., 120m TIR)
- Calibration
- pointing, propulsion
- data rate, electronics miniaturization







Example Future Technologies

- Instrument
  - Stable TIR Detectors
  - Miniature Cryocoolers
  - Calibration Architectures
- Spacecraft
  - Propulsive Capabilities

- Instrument
  - Micro Bolometer Development
  - Refractive Telescope
- Spacecraft
  - Constellation Flying / Propulsion
  - Communication Capabilities

- Instrument
  - Curved Detectors/Large Band Optics
  - Tight Thermal control
- Spacecraft
  - Propulsive Capabilities
  - Communication Capabilities

Imaging Spectroscopy

- Spectrometers have several advantages, even for multispectral measurements
  - Flexible “composite” bandpass definition
  - Ability to acquire narrow-band data for other and new products
  - As # bands increases, instrument design may become simpler than crafting filters for each band and fitting the discrete filters within the FOV of the telescope
    - The band requirements will ultimately let the designers determine where that breakpoint is
  - Potential for improved band-to-band registration and band simultaneity
- But there are technical challenges as well
  - Stray light & non-uniformity for large FOV instruments
  - SNR of narrow-band derived Landsat data is inherently lower for the <u>same sized aperture</u>, due to increase ROIC read-noise in the aggregated product.
    - SNR enhancing FPA features found in many MS designs are not readily achievable, or available, in a spectrograph

Conclusions

- Primary drive has been to reduce Landsat instrument size while maintaining image quality
  - New technologies can help
  - Fundamental restrictions to how small we can go, while obtaining coverage in SWIR and TIR, based on optical physics
    - Some form factors, such as CubeSats, will be severely challenged to provide Landsat quality SWIR and TIR data and 60m TIR is not possible in those small boxes
    - **Full capability instruments that allow the use of an ESPA class bus appear to be feasible in the L-10 and beyond time frame**
- As the science community requires greater and finer spectral coverage, spectroscopy likely to become more advantageous
  - Top level requirements such as RER, SNR, and bandpasses are readily achievable
  - Caveats remain to some of the performance areas such as:
    - spectral uniformity and out-of-band,
    - spatial stray light